Coherent terahertz radiation from $Tl_2Ba_2CaCu_2O_{8+\delta}$ thin films excited by optical laser pulse under magnetic field

Yukihiro Tominari [a,1], Toshihiko Kiwa [a], Hironaru Murakami [a], Masayoshi Tonouchi [a,b], Hagen Wald [c], Paul Seidel [c], Henrik Schneidewind [d]

[a] *Research Center for Superconductor Photonics, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[b] *CREST, Japan Science and Technology Corporation (JST), 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[c] *Institut für Festkörperphysik, Friedrich-Schiller-Universität, Helmholtzweg 5, D-07743 Jena, Germany*
[d] *Institute for Physical High Technology, Department of Cryoelectronics, P. O. Box 100239, D-07702 Jena, Germany*

Abstract

We observed terahertz pulse radiation from $Tl_2Ba_2CaCu_2O_{8+\delta}$ thin films by femtosecond optical pulse excitation under a bias-current condition and a radial magnetic field of ∼100 Oe nearly parallel to the *c*-axis of the film. The observed waveform under magnetic field showed clear oscillations below 80 K, and the Fourier spectrum showed additional peak other than the frequency components observed in the bias-current condition. The additional peak (630 GHz at 24 K) shifted towards lower frequency region with increasing temperature. The observed resonant THz wave behavior is quantitatively explained by Josephson plasma phenomenon.

Key words: High-T_c superconductor, Terahertz radiation, Josephson plasma phenomena

Terahertz (THz) radiation phenomena from semiconductors [1] and high-T_c superconductors (HTSCs) [2] have been energetically investigated at the world wide in recent years, combined to development of femtosecond pulsed laser (FPL) technology. Up to now, we have observed THz wave radiation from current biased $YBa_2Cu_3O_{7-\delta}$ (Y-123) [2,3] or $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) [4]. The THz pulse radiation properties from these HTSCs have been well explained by supercurrent modulation caused by FPL irradiation [2,3].

On the other hand, it has been theoretically predicted that coherent THz electromagnetic wave could be radiated from HTSCs by collective excitation due to Josephson plasma resonance (JPR) [5], and a lot of experimental effort has been made to realize free-space radiation of coherent THz wave by the JPR phenomenon [6,7].

In this paper, we demonstrate THz pulse radiation properties of *c*-axis oriented $Tl_2Ba_2CaCu_2O_{8+\delta}$ (Tl-2212) thin films by FPL illumination. Under the radical magnetic field, we observed a resonant THz pulses probably due to the JPR phenomenon.

C-axis oriented Tl-2212 thin films were grown on $(1\underline{1}02)$ sapphire substrates by a two-step magnetron sputtering method with the intermediating CeO_2 buffer layer. The thickness of the film was 220 nm and critical temperature, T_c, was 99 K [8]. The film was patterned into a bow-tie antenna structure with a bridge of $30\mu m \times 40\mu m$ (width×length) in the central part by means of photolithographic techniques. THz radiation properties were observed by FPL illumination to the bow-tie antenna with applying biased-current or an external radial magnetic field of ∼100 Oe along the *c*-axis. The detailed experimental procedures have been reported elsewhere [3].

Figure 1 shows the waveform of THz pulse radiated under the condition of excitation FPL power 5 mW and biased-current 50 mA at 24 K. In this condition single THz pulse radiation was observed, as has been observed for Y-123 and Bi-2212 [2–4].

[1] E-mail:tominari@rcsuper.osaka-u.ac.jp

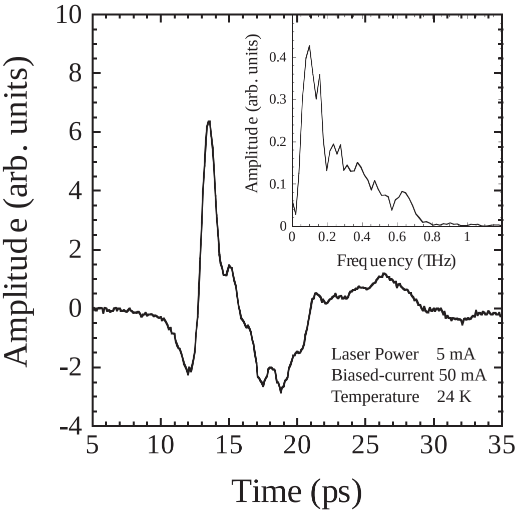

Fig. 1. Typical time-resolved waveform of THz radiation under current biased Tl-2212 bow-tie antenna at $T = 24$ K. The inset shows Fourier spectra obtained from THz waveform by FFT.

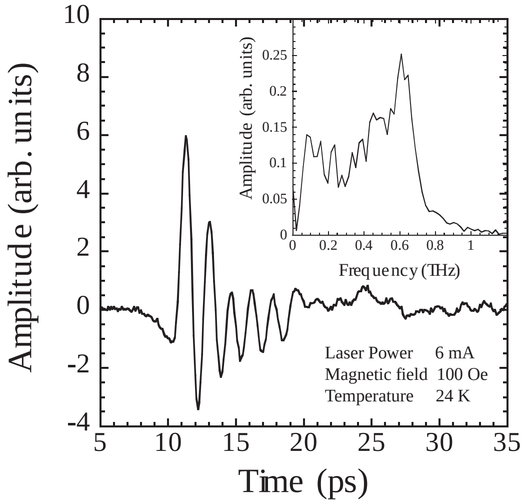

Fig. 2. Time-resolved waveform radiated from Tl-2212 bow-tie antenna under magnetic field (100 Oe // c-axis) at $T = 24$ K. The inset shows its Fourier spectra calculated by FFT.

Figure 2 shows a typical THz waveform emitted from a Tl-2212 thin film under the radial magnetic field. The leading pulse around 11 ps followed by the resonant oscillations can be seen.

To get more detailed properties of the signals emitted from Tl-2212, the Fourier components were obtained through a fast Fourier transformation (FFT) of the waveform. The insets in Figs. 1 and 2 show the FFT spectra obtained under the respective conditions. The former shows the central frequency of $\sim$100 GHz with the cut-off frequency of $\sim$700 GHz. The central frequency was temperature- and bias-current-independent as observed for Y-123 and Bi-2212 [2–4]. Whereas, the latter shows, besides the peak around $\sim$100 GHz, an additional peak at about 620 GHz due to the resonant oscillations with the cut-off frequency of $\sim$700 GHz. The additional peak in the FFT spectrum shifted towards lower frequency region with increasing temperature (around 300 GHz at 80 K) and vanished above T_c [9]. On the other hand, the peak around 100 GHz remains temperature independent till it disappeared above T_c as observed made the bias-current condition. It was also observed that the oscillation frequency tends to decrease with increasing excitation laser power [9].

If the measured resonant THz wave radiation is related to the JPR, London penetration depth along the c-axis, λ_c, can be estimated from the relationship, $\lambda_c = c/\omega\sqrt{\epsilon}$, where ω is the resonant frequency, c is light speed and ϵ is the dielectric constant. Using $\epsilon = 9.1$ [10], λ_c can be estimated as $\sim$26 μm at 24 K and $\sim$53 μm at 80 K. These values show a good agreement with those reported on Tl-2212 previously [11].

In summary, we observed resonant THz radiation from Tl-2212 thin films by FPL illumination under a radial magnetic field, which is quantitatively explained by the JPR phenomenon. The most important result obtained in the present study is that the resonant THz wave was radiated into free-space by the FPL excitation.

Acknowledgements

This work was supported in part by a Grant-in-Aid for Scientific Research (B) No.12450146 and No.13555107 from the Japan Society for the Promotion of Science, and on project No.14655121 from Ministry of Education, Culture, Sports, Science and Technology of Japan, and by the Murata Science Foundation.

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